6th International Conference on Hyperons, Charm and Beauty Hadrons

Standard-Model Higgs Searches at CDF Run II

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on behalf of the

CDF Collaboration

BEACH 04

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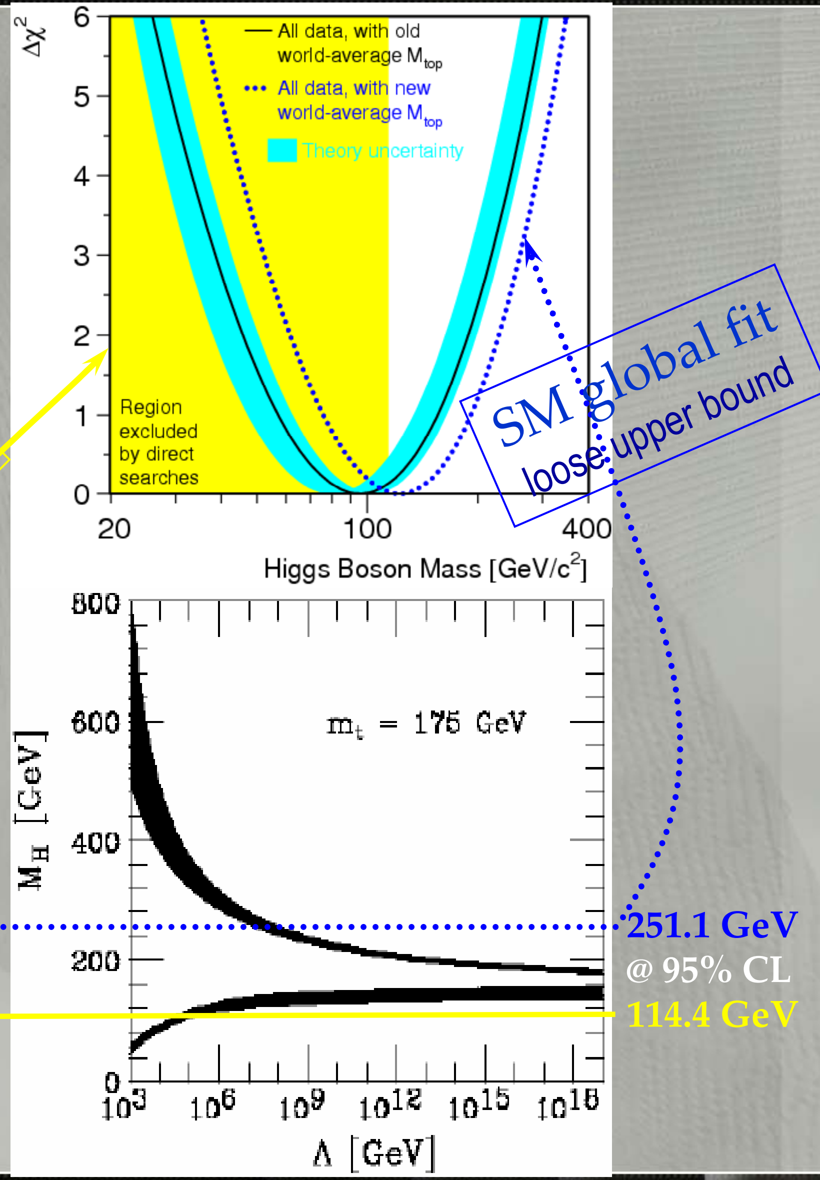
Outline

- Introduction
- About the SM Higgs Boson
- Existing SM Higgs Results
- Higgs Sensitivity at TeVatron
- TeVatron Performance
- CDF II Detector
- CDF II Overall Higgs Search Status
- CDF II SM WH→lνbb Analysis
- CDF II SM H→WW→lνlν Analysis
- Conclusion

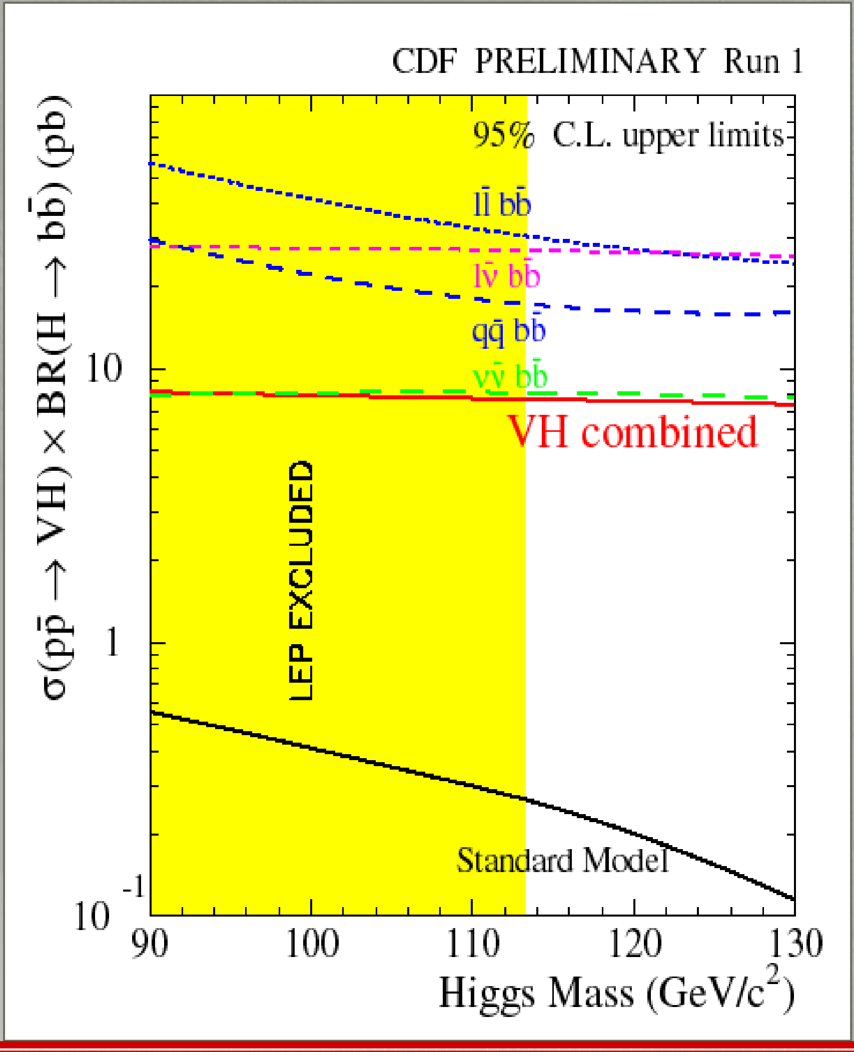
Introduction

- **Standard Model has explained well high-energy phenomena so far.**
  - Higgs boson remains un-observed – last missing piece.
- Higgs boson is the source of **electroweak symmetry breaking dynamics**.
  - hence responsible for the **mass generation of electroweak gauge bosons and fermions**.
- Higgs boson mass can be an **indicator of new physics** where the Standard Model will fail.
  - ➢ $\mathbf{M_H}$ is critical to the determination of $\mathbf{\Lambda}$, the energy scale at which SM holds no more. Could SM still work at the Plank scale (10^{19} GeV)?



Run I SM Higgs Results

- measured in four channels:
  - WH → lvbb – higher limits due to slight fluctuation up
  - ZH → l^+l^-bb
  - ZH → vvbb – lowest limits
  - VH → qqbb
- used $L_{int} \leq 106 \pm 4\ pb^{-1}$
- binned likelihood in di-jet mass M_{bb} for setting limits
- $\sigma \cdot BR_{comb} \sim 15\text{-}50\ \sigma \cdot BR_{SM}$, still far from examining the SM prediction



benchmark : $\sigma(p\bar{p} \to VH) \cdot BR(H \to b\bar{b}) < 7.4$ pb @ 95% CL for $M_H = 130$ GeV

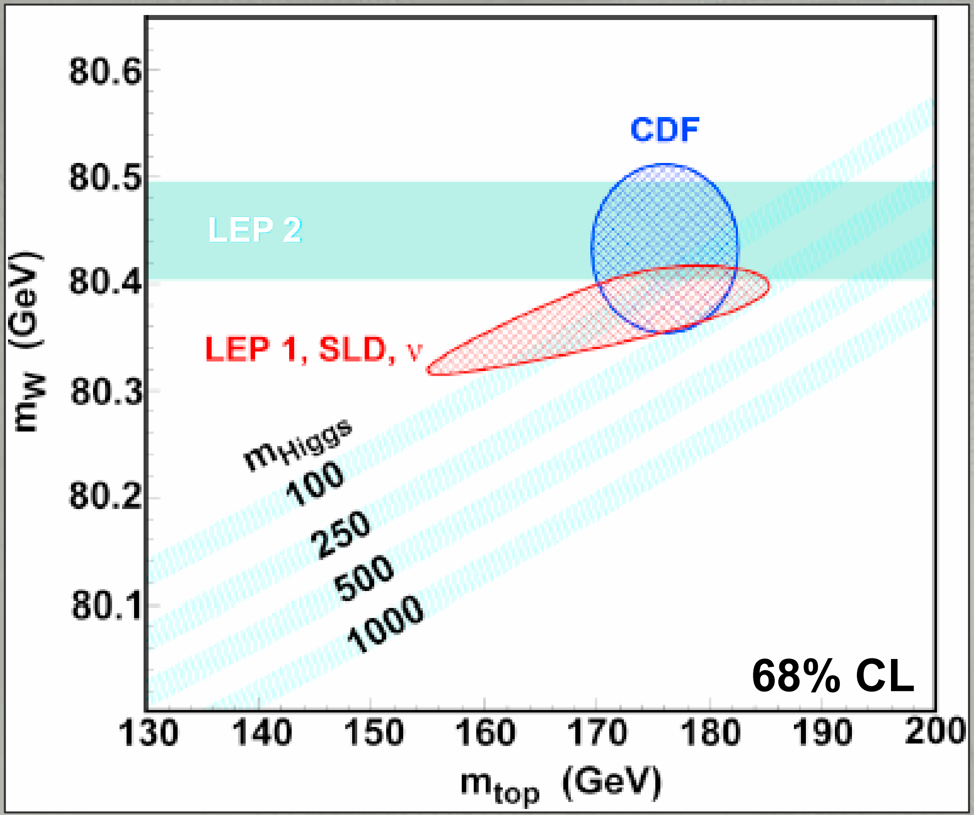
Electroweak Constraints

Precision measurement of electroweak parameters, such as

- M_{top} the top quark mass
- M_W the W boson mass

leads to tight constraints on M_H the Higgs mass.

Another Thing CDF (and D0) Can Do Well



light Higgs preferred by data

$$\delta M_W \propto (M_{top}^2, \ln(M_H))$$

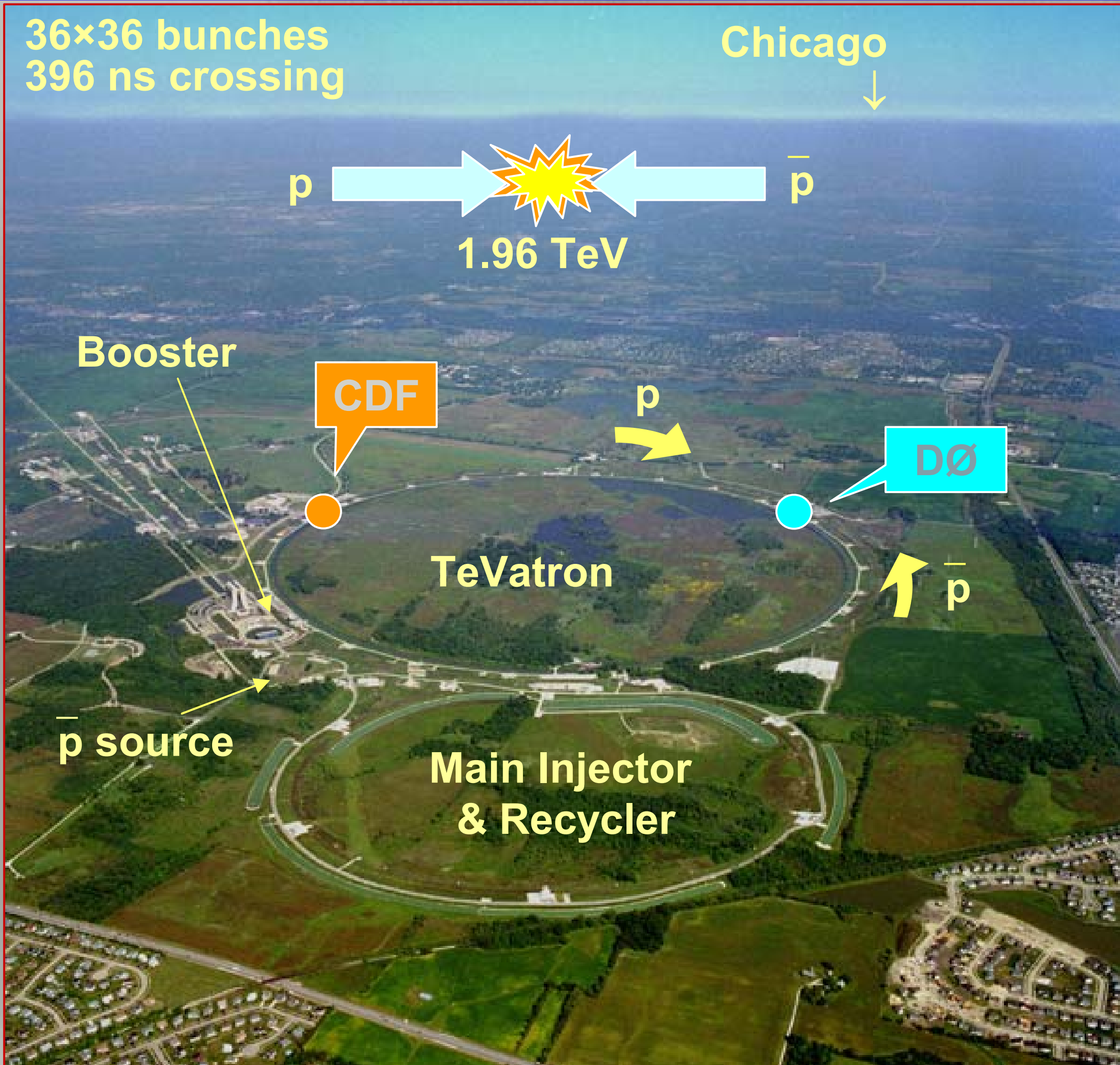
quadratic

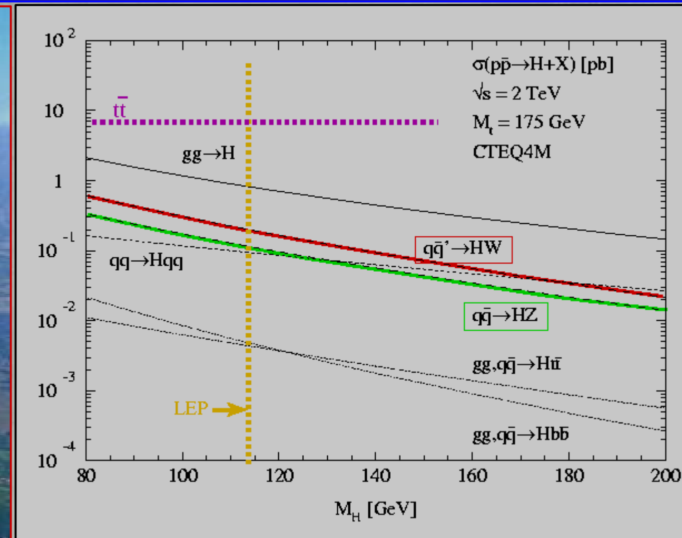
logarithmic

M_{top} reduced by 5 GeV, M_H limit reduced by 35 GeV

TeVatron

TeVatron is currently the only place capable of probing the Higgs sector





In comparison to Run I:

luminosity ↑ > 20X

σ(gg→H) ↑ 40%

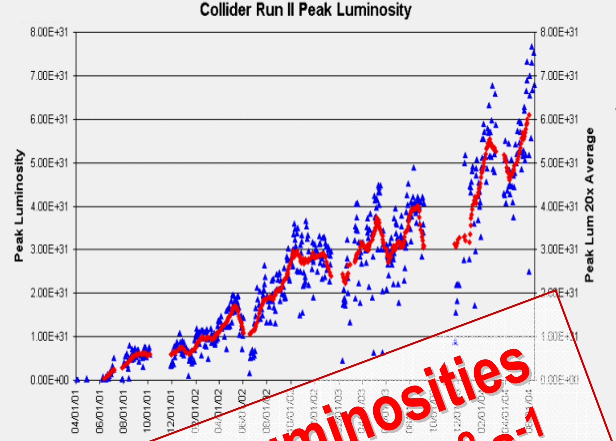
σ(qq→VH) ↑ 20%

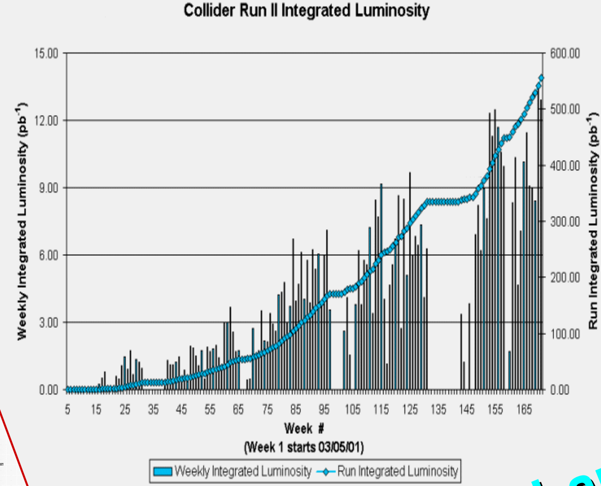
b trigger and tagging ↑

E_{jet} resolution ↑

lepton acceptance ↑

Luminosity



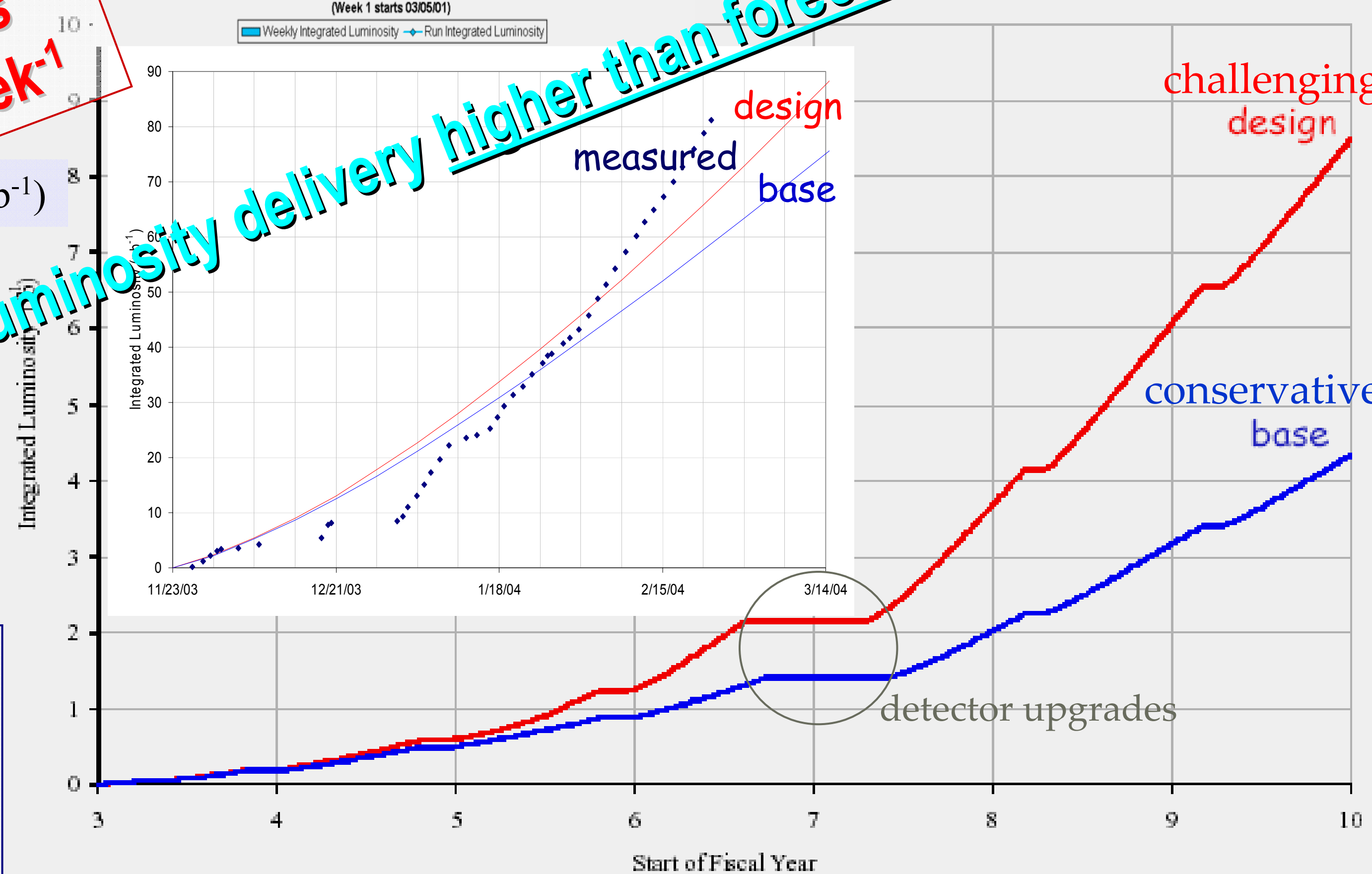


Record Luminosities

L_{ins} = 9 x 10^{31} cm^{-2} s^{-1}

L_{int} = 13.5 pb^{-1} week^{-1}

TeVatron has had luminosity delivery higher than forecast since early 2004



Possible to Reach
L_{int} = 2 fb^{-1} / 8 fb^{-1}
End of Run II A/B

Higgs Sensitivity at TeVatron

with the upgraded detectors and improved b-tagging efficiency, we need 20% less luminosity than SHWG's estimate in 98-99 to reach the SM-sensitive zone, combining all the bests we can do, including search channels and experiments.

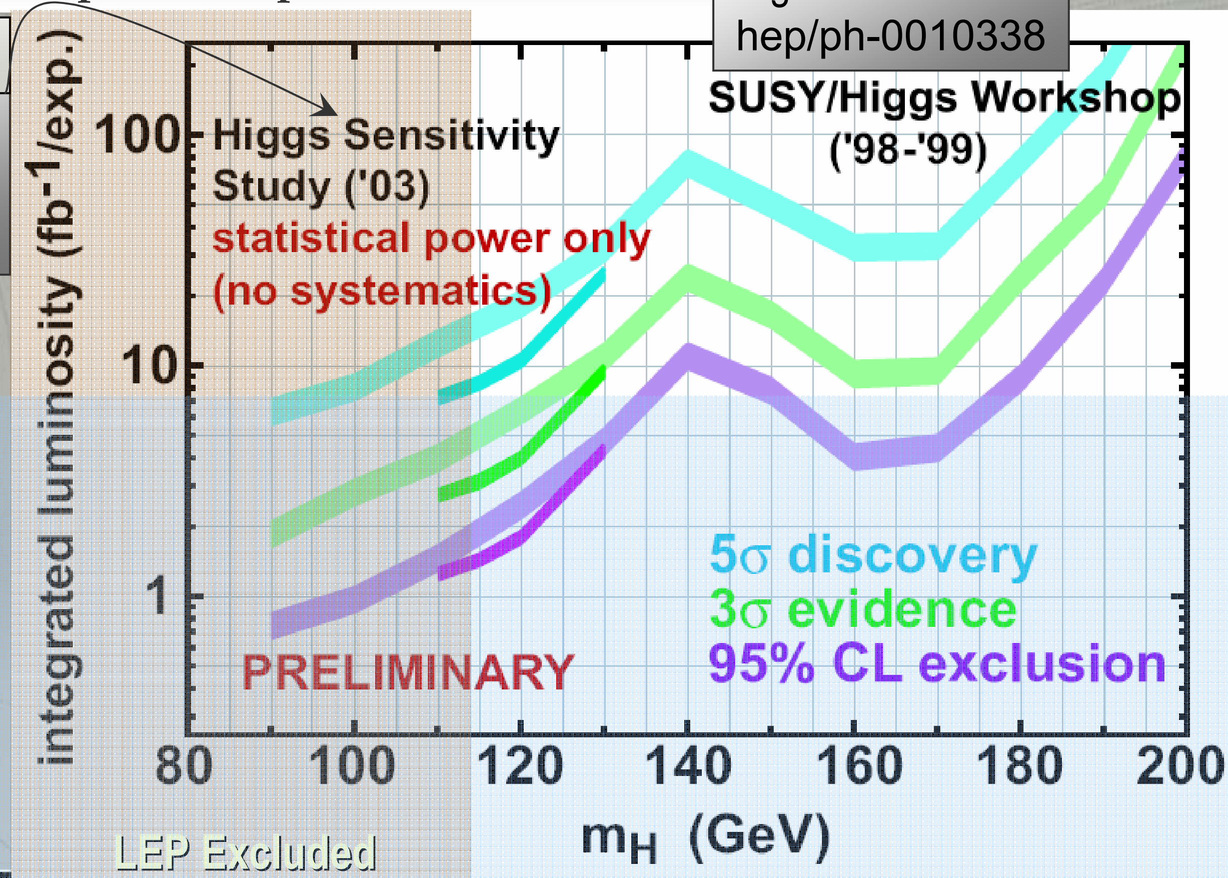
L_{int} threshold ≡ 50% pseudo-experiment satisfaction

investigated all the good channels
hep/ph-0010338

understood Run II condition better

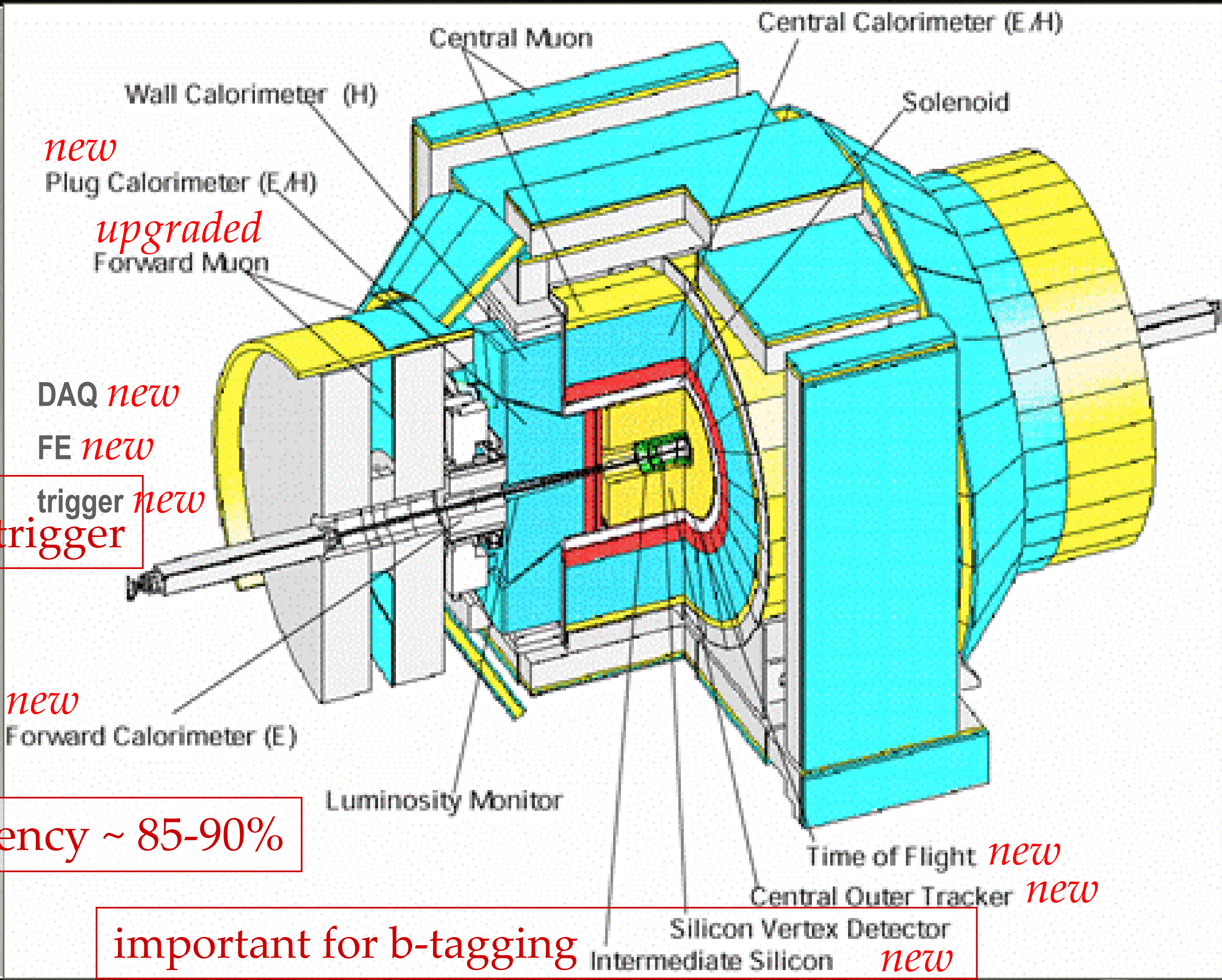
given short time, focused on SM WH→lvbb & ZH→vvbb
FERMILAB-PUB-03-320-E

Run II Possible?



CDF II Detector

Higgs analyses demand every component of the detector!!!!!

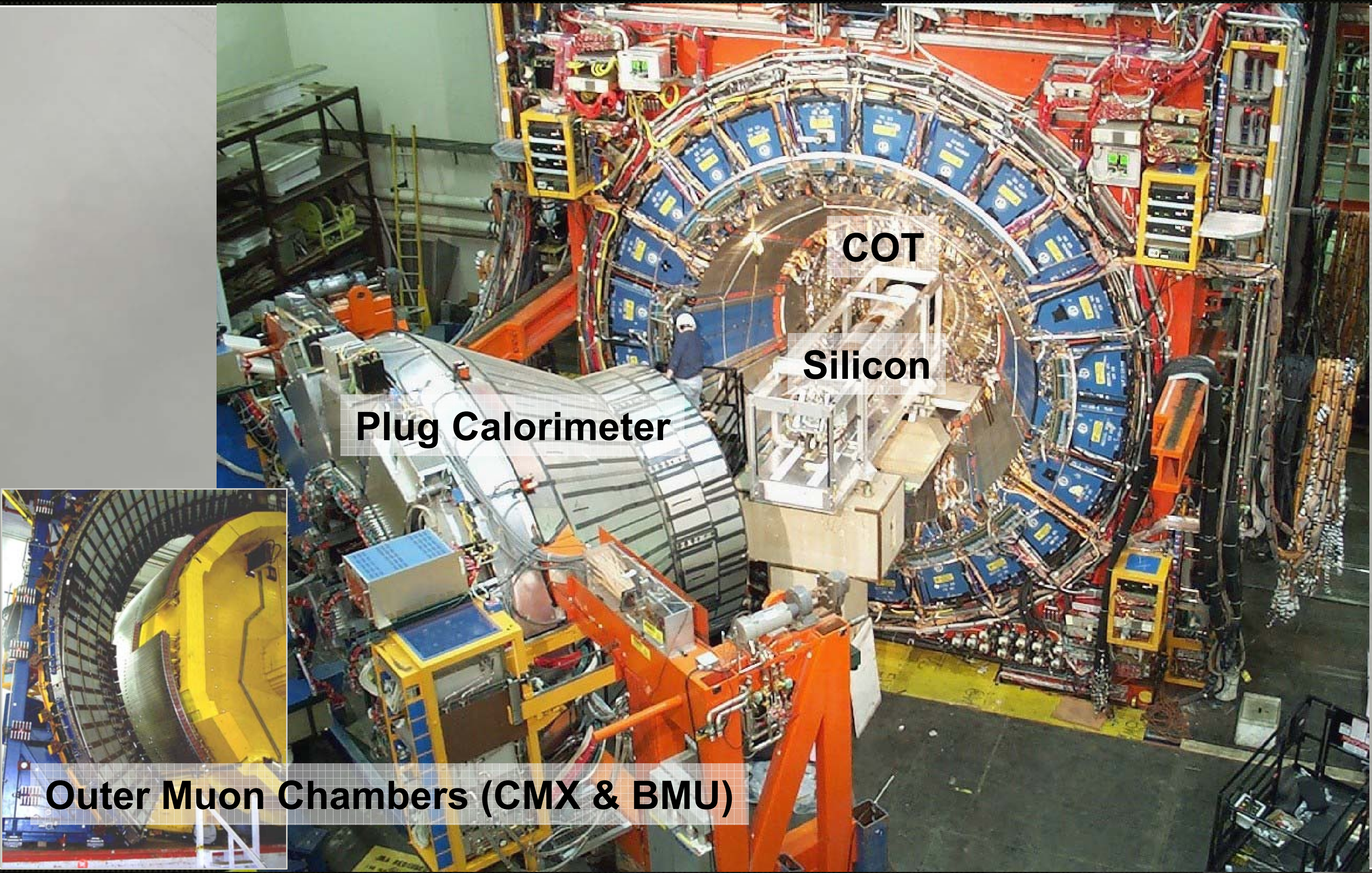


displaced-track trigger

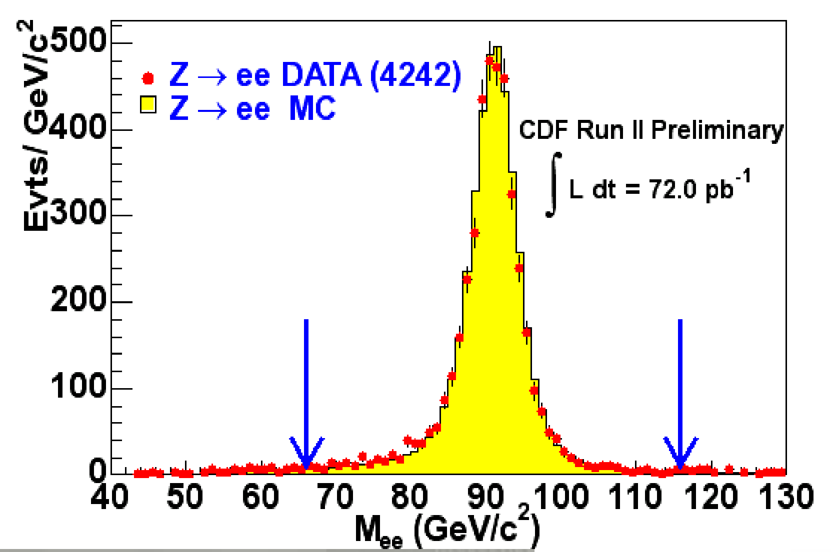
data-taking efficiency ~ 85-90%

important for b-tagging

CDF II Detector

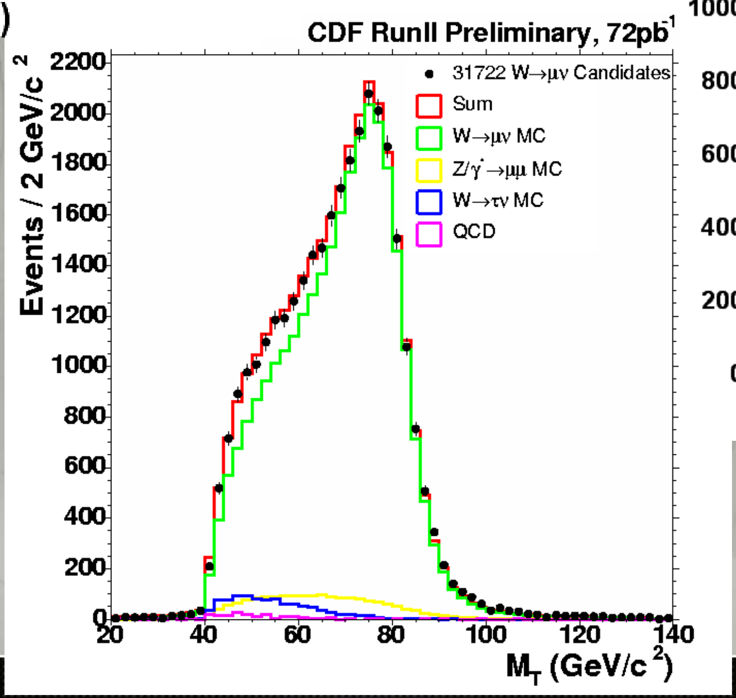


Lepton ID at CDF II

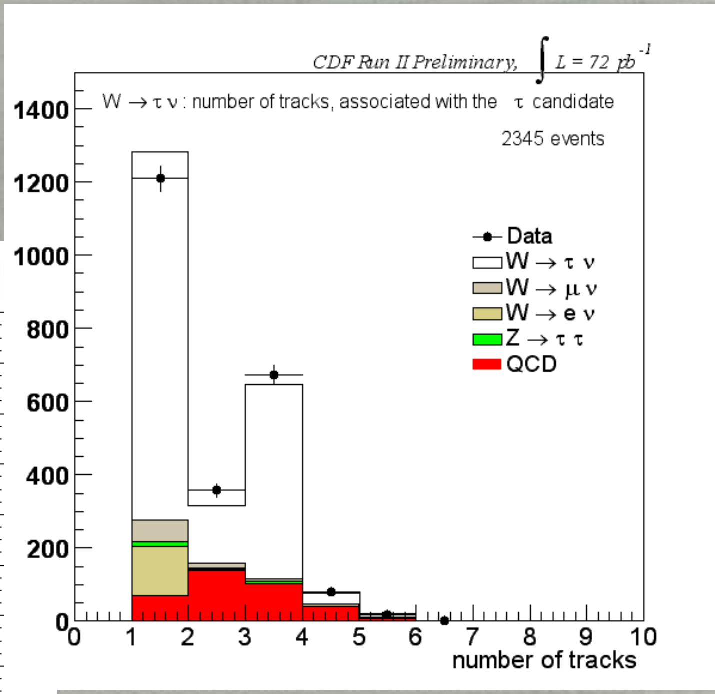


we are doing very well
on lepton identification

electrons



muons



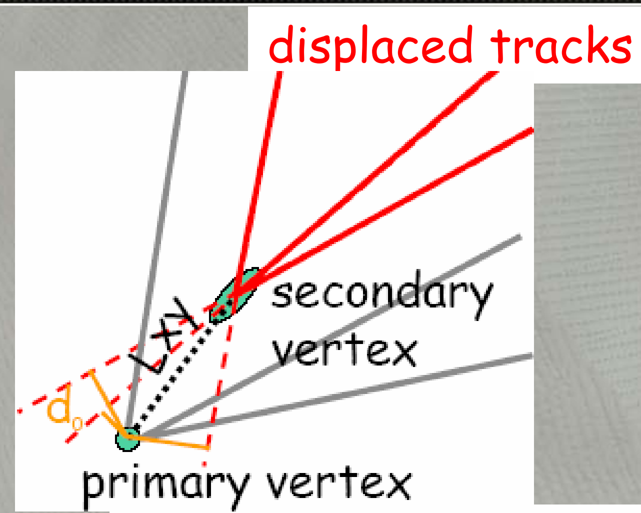
tauons

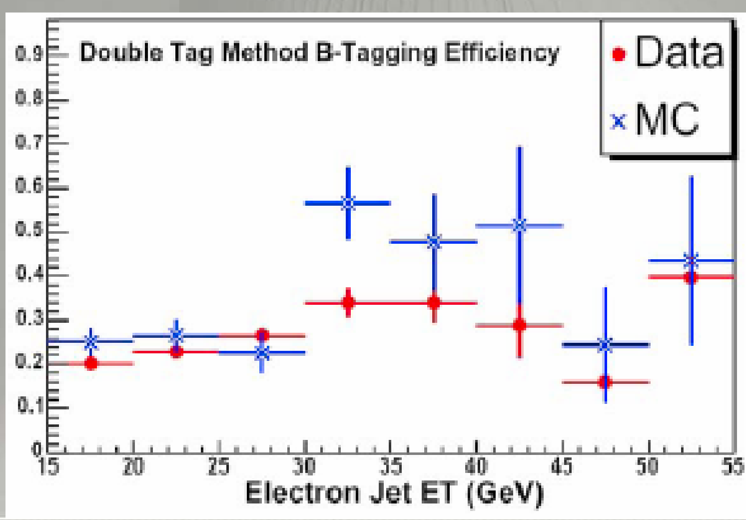
b-Tagging at CDF II

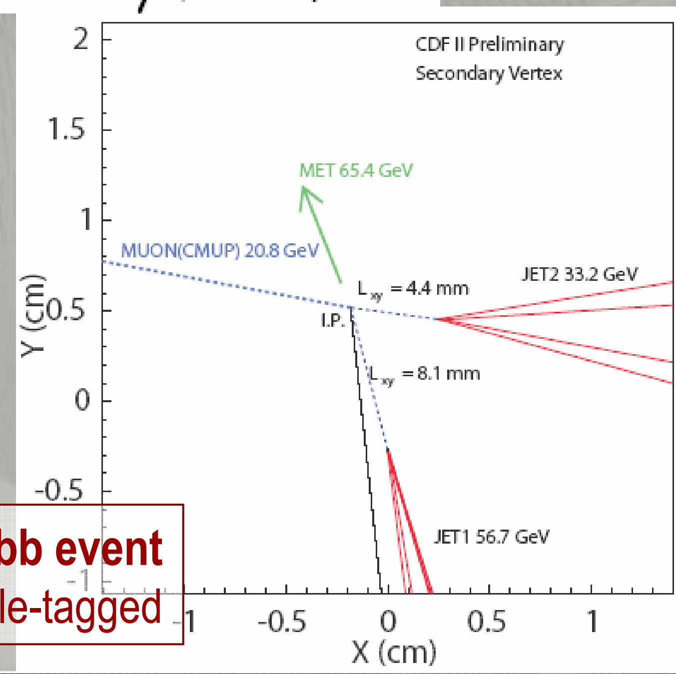
B hadron's flight time cτ ~ 450 μm
⇒ Lxy ≡ cτ·βγ can be detected by SVX II
and used for b-tagging

secondary vertex algorithm:
1) Select tracks that have large impact parameter d_0
2) Apply a vtx fitting algorithm to reconstruct a displaced vertex

b-jets are tagged with Sec.Vtx.Alg.





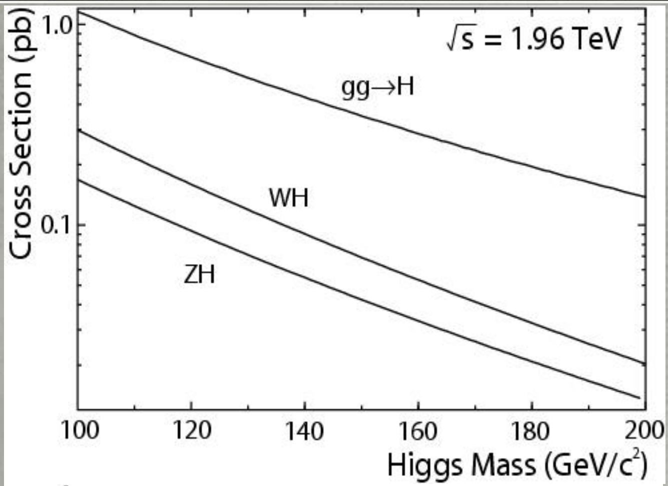


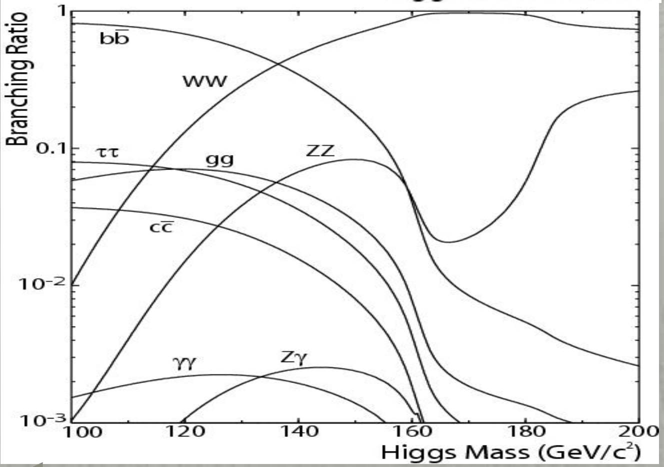
a μνbb event
double-tagged

CDF II Higgs Project

- SM ZH→llbb where l={e, μ}
- SM ZH→ννbb
- SM WH→lνbb
- SM WH→WWW→l±νl±νjj
- SM H→WW→lνlν
- MSSM H→ττ @ large tanβ
- MSSM Hbb→bbbb @ large tanβ
- SUSY L-R symmetric $H^{++}\rightarrow l^+l^+$
- 2HDM H^+
- LFV Higgs

searching
searched
will search





$H \rightarrow \bar{b}b$

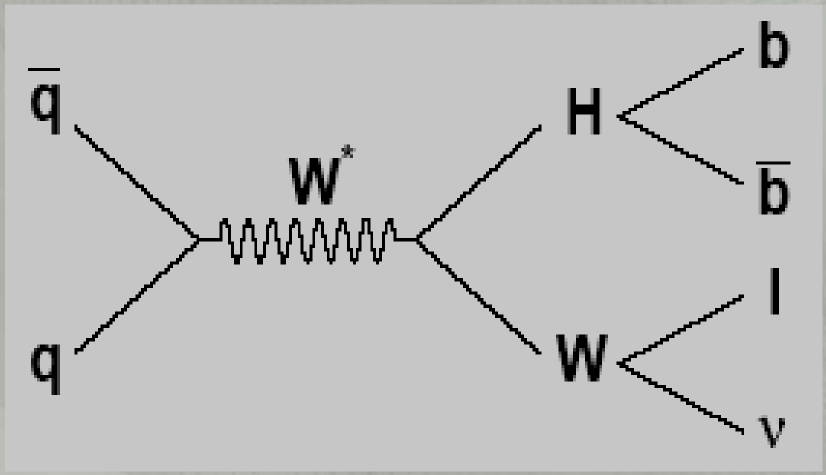
$H \rightarrow WW^{(*)}$

dominant decay modes

SM WH→lνbb Search at CDF II

WH→lνbb

- Golden channel of Higgs boson search at TeVatron
  - Largest branching ratio for $M_H < 135$ GeV
  - Second largest cross-section
  - Not so bad QCD background as gg→H→bb
  - Highest achievable $S/\sqrt{(S+B)}$ in the most-favored Higgs mass region
- 162 pb^{-1} data collected from Feb 02 to Sep 03
- Alpgen and Herwig MC plus detailed detector simulation

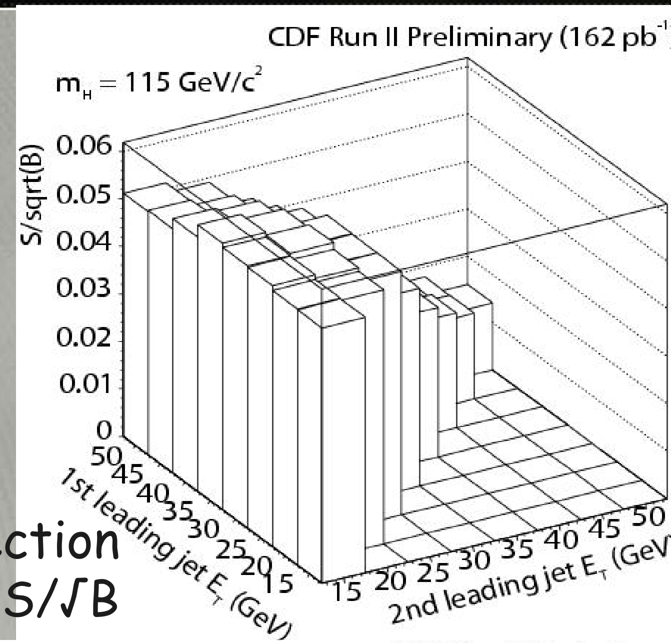


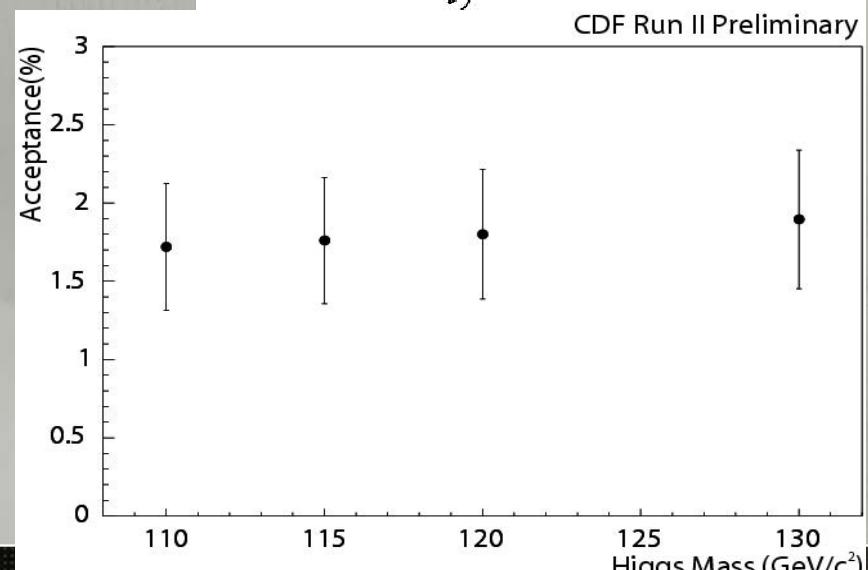
WH→lvbb

Event Selection –

- One central isolated non-conversion electron or non-cosmic muon
- Lepton Et > 20 GeV
- Missing Et > 20 GeV
- Jet Et > 15 GeV
- Jet |η| < 2.0
- Two jets, at least one b-tagged

looser jet selection enables higher S/√B



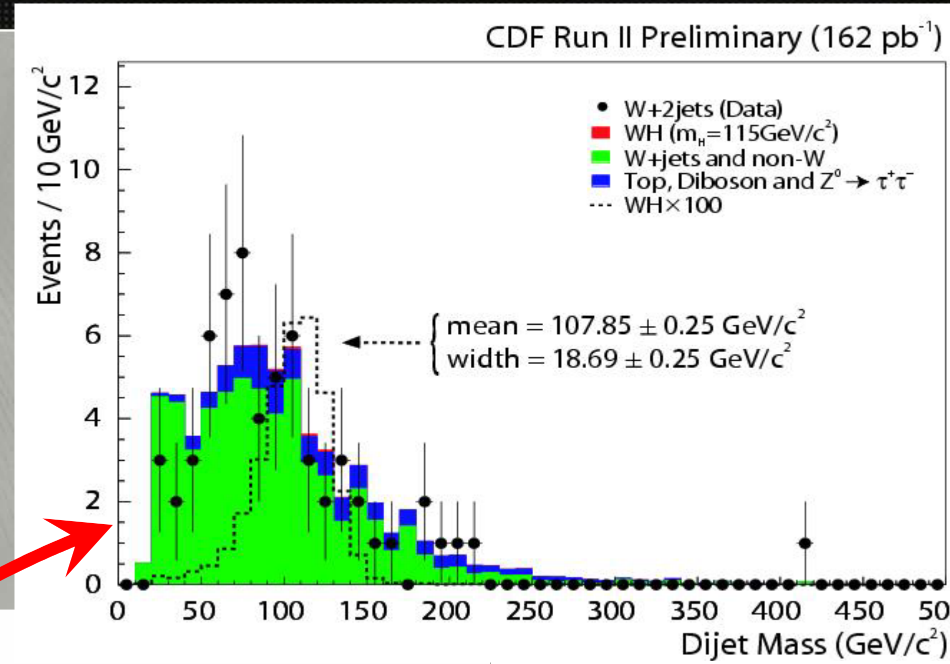


total WH acceptance ~ 1.8 ± 0.4 %

WH→lvbb

used the W+2jets bin to set limits on WH production:

- expected **~0.29** signal events
- expected **~60.6** background
- observed **62** events from data



CDF Run II Preliminary (162 pb^{-1})

Background	$W^\pm$ + 1 jet	$W^\pm$ + 2 jets	$W^\pm$ + 3 jets	$W^\pm$ + $\geq$ 4 jets
Events before tagging	13417	2072	313	82
Mistags	36.20 ± 5.40	14.07 ± 2.10	3.97 ± 0.68	2.04 ± 0.39
$W^\pm + b\bar{b}$	18.58 ± 4.82	12.05 ± 2.19	2.82 ± 0.57	0.99 ± 0.25
$W^\pm + c\bar{c}$	9.44 ± 2.94	5.19 ± 1.14	1.04 ± 0.25	0.35 ± 0.11
$W^\pm + c$	33.08 ± 7.83	7.86 ± 2.08	1.36 ± 0.39	$0.28 \pm$ [illegible]
Diboson/$Z^0 \rightarrow \tau^+\tau-$	1.74 ± 0.3[illegible]	2.25 ± 0.34	0.59 ± 0.13	[illegible] ± 0.03
QCD	$22.24 \pm$ [illegible]	10.31 ± 1.66	2.44 ± 0.57	[illegible]$.58 \pm 0.18$
$t\bar{t}$	[illegible] ± 0.07	5.05 ± 0.64	$12.65 \pm$ [illegible]	20.10 ± 2.49
single top	[illegible]$.14 \pm 0.15$	3.76 ± 0.49	0.90 ± 0.12	0.17 ± 0.03
Total Background	122.84 ± 11.40	60.55 ± 4.43	25.77 ± 2.16	24.62 ± 2.59
Observed positive tags	135	62	23	21

low S/√B

$t\bar{t}$ dominated

data agrees with MC well

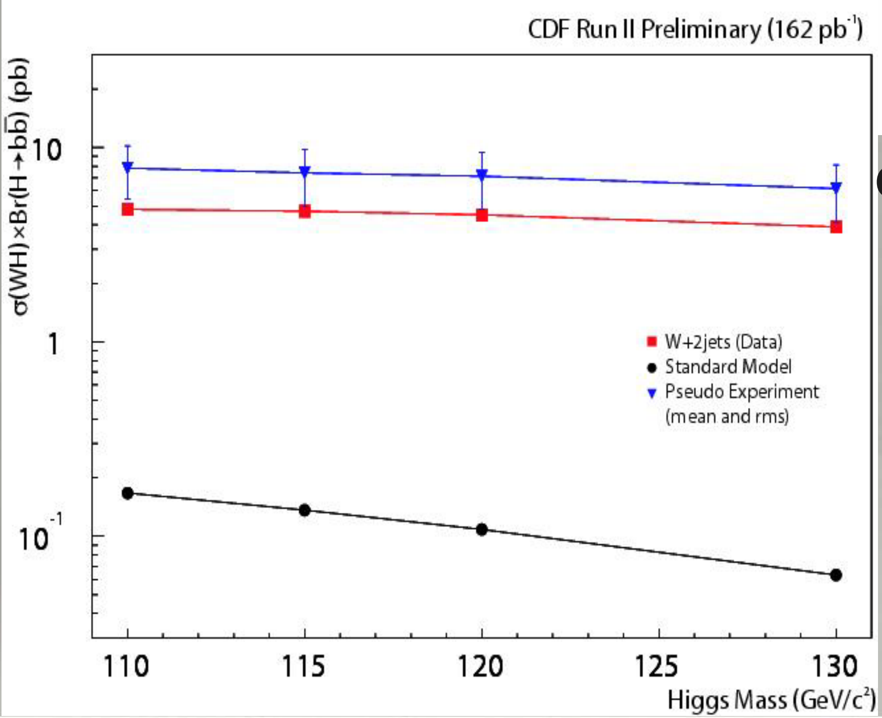
main backgrounds

- W+jets
- mis-tag
- QCD and top

WH→lvbb

- Run I 95% CL limits: 14–19 pb
- Run II:

M_H (GeV)	110	115	120	130
σ·B (pb) <	4.8	4.7	4.5	3.9



source	CEM	CMUP	CMX
Lepton ID	5%		
Trigger	0.06%	0.79%	0.63%
PDF	1%		
ISR/FSR	19%		
Jet	3%		
SECVTX	8.6%		
Jet Energy Smearing	1%		
Total	22%		

estimated systematic uncertainties

- binned max likelihood

$$L = \prod_{bin} u^N e^{-u} / N!$$

where u is the number of expected S+B and N the number of observed events in each mass bin.

WH→lvbb

- great improvement on production limits
- owing to improvement on
  - di-jet mass resolution
  - limit extraction skill
- advancements are planned on
  - plug electron inclusion
  - b-tagging
  - jet energy resolution

currently using only calorimeter info; planning to integrate tracker info later

Results Are Not Final

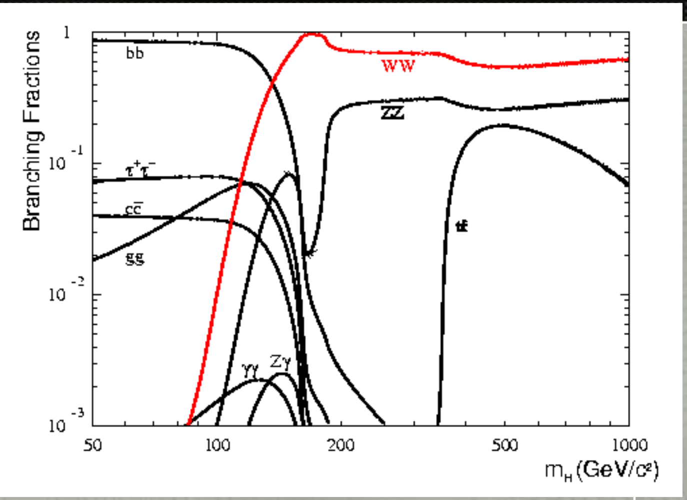
In $m_H = 115$ GeV/c^2 case,

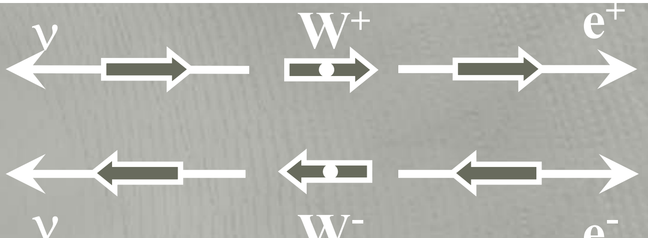
	Run2	Run1		Higgs sensitivity report	
	This Analysis	Cut Based	NN	CASE 0 †	
Mass Resolution	17%††	15%	15%	15%	10%
S	0.29	0.31	0.24	0.13	0.13
B	28.3	50.7	18.3	3.2	2.1
$S/\sqrt{B}$	0.052	0.04	0.056	0.075	0.09

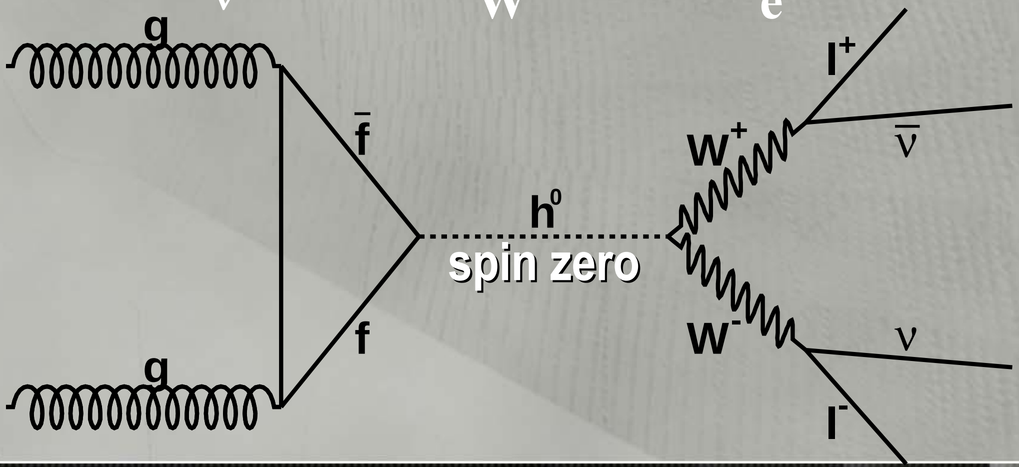
SM $H \rightarrow WW \rightarrow lvlv$ Search at CDF II

H→WW→lνlν

- platinum **for M_H > 135 GeV**
  - Largest branching ratio
  - Largest cross-section
  - No QCD contamination in dilepton final state
- inherited very good control of WW background from the analysis of CDF II WW cross-section measurement
- powerful Higgs discriminator – spin zero
- 184 pb^{-1} data collected from May 02 to Sep 03
- used PYTHIA MC with NLO correction through detailed detector simulation (cdfSim)





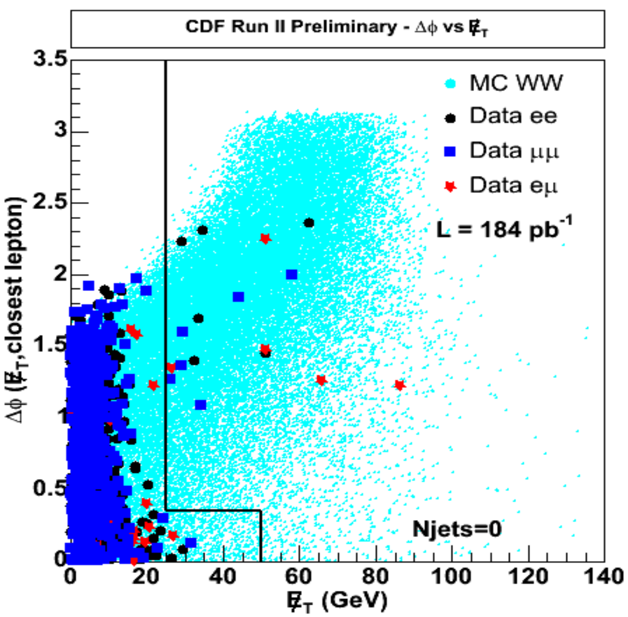


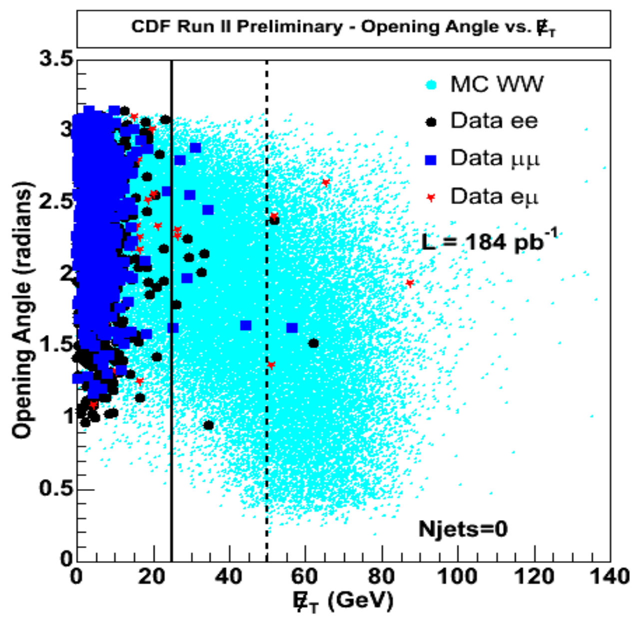
H→WW→lvlv

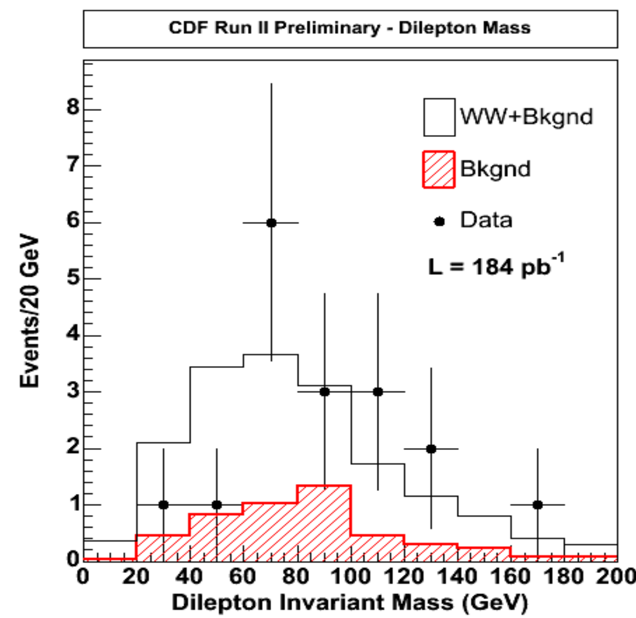
plots from the analysis of WW cross-section measurement showing the major background of H→WW is under control

CDF measures $\sigma(p\bar{p} \to WW) \;=\; 14.3^{+5.6}_{-4.9}\ \text{(stat)} \pm 1.6\ \text{(syst)} \pm 0.9\ \text{(lum)}\ \text{pb}$

in agreement with the Standard Model prediction

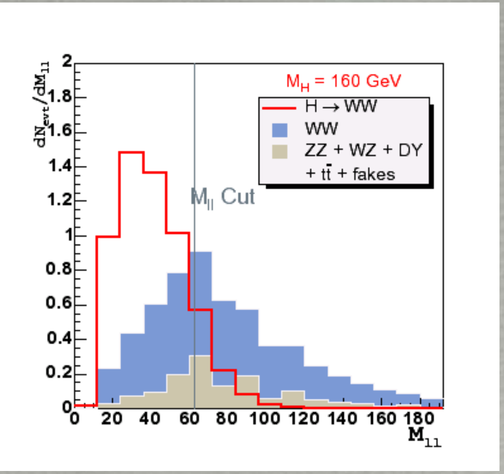






H→WW→lνlν

- **select events** with
  - "well-detected" 2 electron/muons
  - lepton Et > 20 GeV
  - $|\eta_e| < 2.0$; $|\eta_\mu| < 1.0$
  - opposite charge signs, $l^+ l^-$
  - missing Et (met) > 25 GeV
  - no jets with Et > 15 GeV and $|\eta| < 2.5$
  - $\Delta\Phi$(met, lep/jet) > 20° for met < 50 GeV
  - dilepton invariant mass $M_{ll} < \sim\frac{1}{2} M_H$



MC study shows the tendency of small H→WW dilepton invariant mass, which is not a property of other SM background processes..

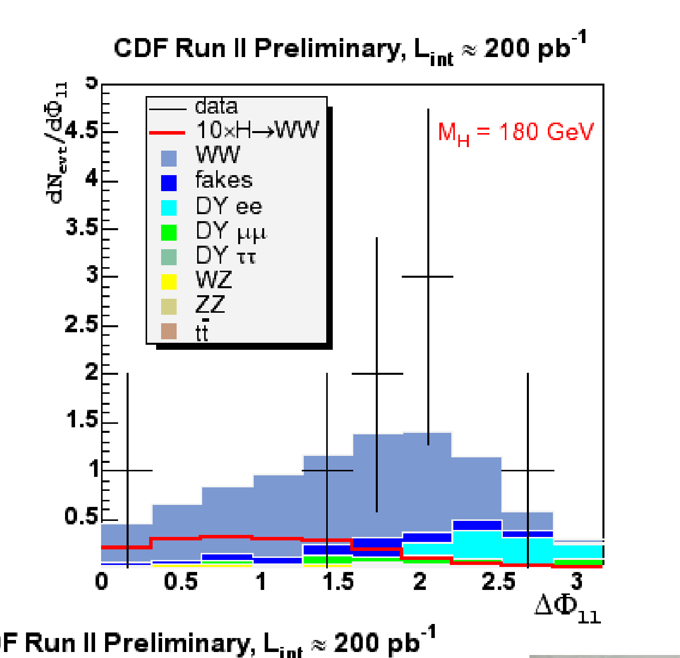
- use a **binned maximum likelihood** method on **dilepton azimuthal angular separation $\Delta\Phi_{ll}$** distribution of selected events to extract **95% CL limits** on $\sigma \cdot BR(gg \to h^0 \to WW)$

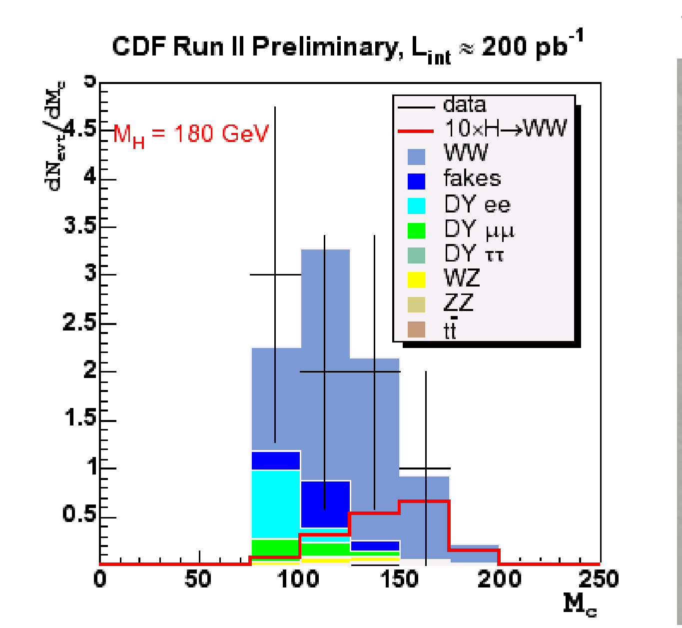
H→WW→lνlν

M_H (GeV)	180
ttbar	0.02 ± 0.01
ZZ	0.06 ± 0.01
WZ	0.18 ± 0.02
DY ττ	0.03 ± 0.01
DY μμ	0.43 ± 0.19
DY ee	0.87 ± 0.44
fakes	0.81 ± 0.25
WW	6.49 ± 0.76
total bg	8.90 ± 0.98
HWW	0.17 ± 0.02
data	8

signal and background expectations

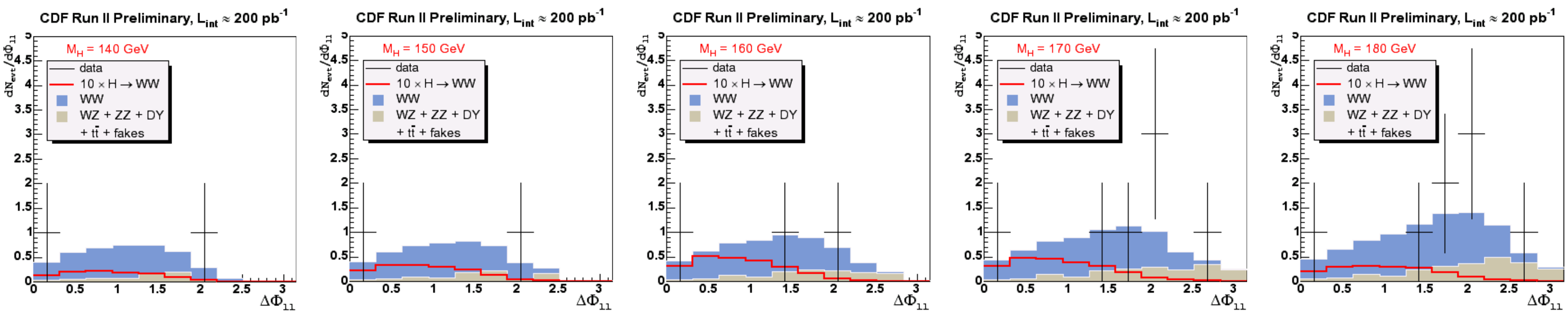
M_H = 180 GeV as an example





cluster mass $M_C \equiv \sqrt{(pt_{ll}^2 + M_{ll}^2)}$ + missing Et

H→WW→lνlν



On fitting $\Delta\Phi_{ll}$ distributions

We separate the to-be-fitted into 4 classes according to expected distribution shapes:

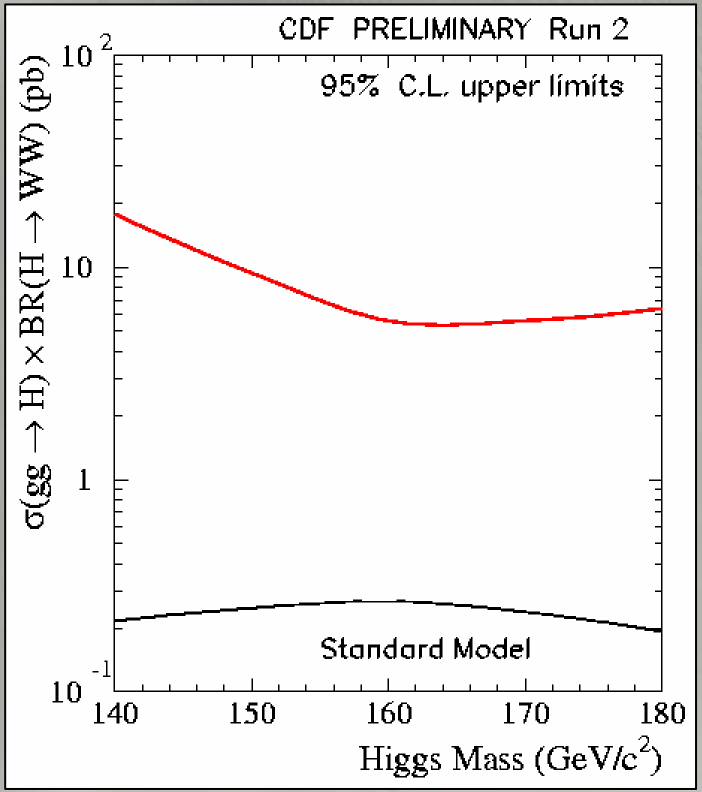
- data – in question
- H→WW – small $\Delta\Phi_{ll}$
- WW – large $\Delta\Phi_{ll}$
- sum of other SM – any

CDF Run II Preliminary

M_H (GeV)	140	160	180
σ(gg→h^0) (pb)	0.45	0.30	0.21
BR (h^0→WW)	0.48	0.90	0.94
L_{int} (pb^{-1})		184 ± 11	
acceptance (%)	0.124±0.012	0.402±0.040	0.449±0.045
SIGNAL (evt)	0.10 ± 0.01	0.22 ± 0.03	0.17 ± 0.02
WW BG (evt)	3.51 ± 0.41	4.45 ± 0.52	6.49 ± 0.76
other BG (evt)	0.68 ± 0.16	1.34 ± 0.35	2.40 ± 0.55
observed (evt)	2	3	8
95% C.L. limit – counting (pb)	18.4	6.2	8.8
expected limit – ΔΦ-fitting (pb)	18.1	6.0	8.0
95% C.L. limit – ΔΦ-fitting (pb)	17.8	5.6	6.4

H→WW→lνlν

- No Run I Results
- Run II



CDF Run II Preliminary, $L_{int} \approx 200\ pb^{-1}$

M_H (GeV)	140	150	160	170	180
σ·B (pb) <	17.8	9.4	5.6	5.6	6.4

Results Are Not Final

can be advanced

by way of

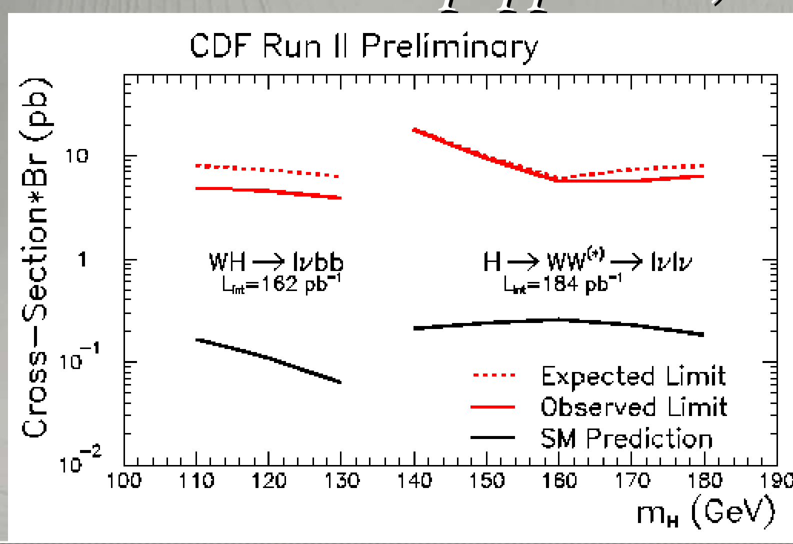
- lowering final-state lepton pt(s)
- including jet bin(s)
- cutting on more variable(s) that discriminates Higgs signal from backgrounds, e.g. M_C
- extending to lower Higgs mass

Conclusion

SM Higgs hunting in Run II at CDF has started.

- We need more data.
- Sensitive tests of the Standard-Model Higgs sector is possible at TeVatron Run II, with designed luminosity and full strength of both experiments.
- We should/can now set constraints on the Higgs mass with precision top and W measurements.

First results have popped out, to our excitement.



more will follow

Backup

TABLE 28. Summary of the optimized cuts additional to those in Eqs. (68)–(74) for various Higgs boson mass.

m_h [GeV]	140	150	160	170	180	190
$\cos\theta^*_{\ell_1}$	-	<0.6	0.35	0.35	0.55	0.75
$\not{E}_T$	>25	25	30	35	40	40
$\min[M_T(\ell_1\not{E}_T), M_T(\ell_2\not{E}_T)]$	>40	40	75	80	85	75
$M_T(\ell_1\not{E}_T)$	>60	60	-	-	-	-
$m(\ell\ell)$	<65	65	65	75	85	-
$p_T(\ell\ell)$	>40	50	65	70	70	70
$\theta(\ell\ell)$	<100	100	70	70	90	90
M_T	-	>110	120	130	140	140

TABLE 29. Summary table for $h \to W^*W^* \to \ell\bar{\ell}\nu\bar{\nu}$ signal for $m_h = 140$–190 GeV and various SM backgrounds after the kinematic cuts of Eqs. (68)–(74) and the likelihood cut Eq. (77). The entry "fake $j \to e$" refers to the background where a jet mimics an electron with a probability of $P(j \to e) = 10^{-4}$. The backgrounds are independent

Sensitivity Factors in H→WW→lvlv

with good lepton ID

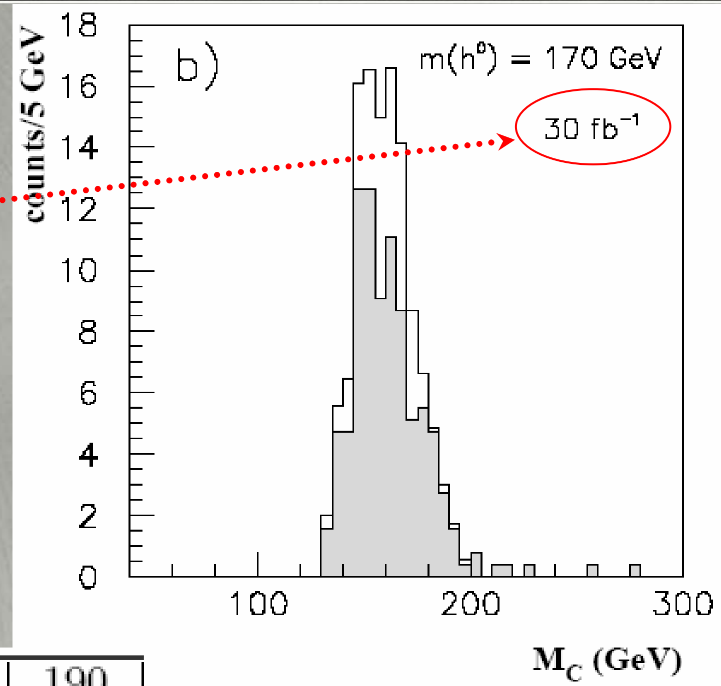
and specific cuts on

the kinematics among final-state leptons

and missing Et as function of the Higgs

mass, substantial S/√B can be achieved

NOTE: SHWG's estimate was based on abundance of integrated luminosity...



m_h [GeV]	140	150	160	170	180	190
$gg \to h$ [fb]	2.2	2.4	1.3	0.93	0.85	0.73
associated VH [fb]	0.26	0.31	0.13	0.09	0.06	0.06
VV fusion [fb]	0.12	0.12	0.09	0.06	0.05	0.05
signal sum [fb]	2.6	2.8	1.5	1.1	0.96	0.83
SM backgrounds [fb]	39	27	4.1	2.3	3.8	7.0
fake $j \to e$ [fb]	5.1	3.4	0.34	0.15	0.08	0.45
backgrounds sum [fb]	44	30	4.4	2.4	3.8	7.5
S/B	0.058	0.094	0.34	0.45	0.25	0.11
$S/\sqrt{B}$ for 30 fb^{-1}	2.1	2.8	3.9	3.8	2.7	1.7

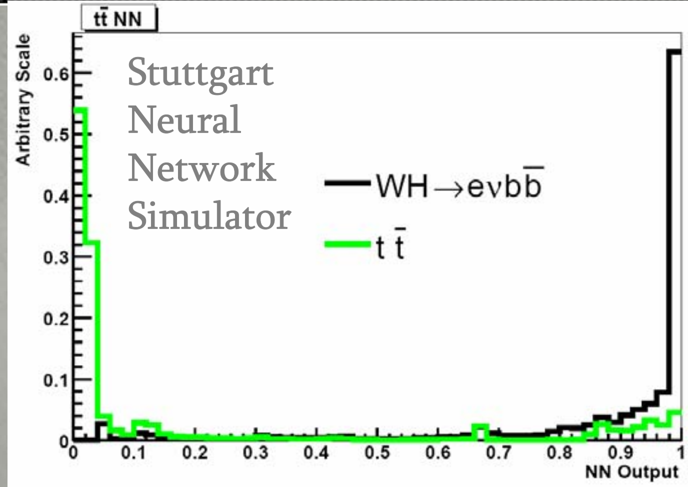
cluster mass

$$M_C \equiv \sqrt{(pt_{ll}^2 + M_{ll}^2)} + \text{Missing Et}$$

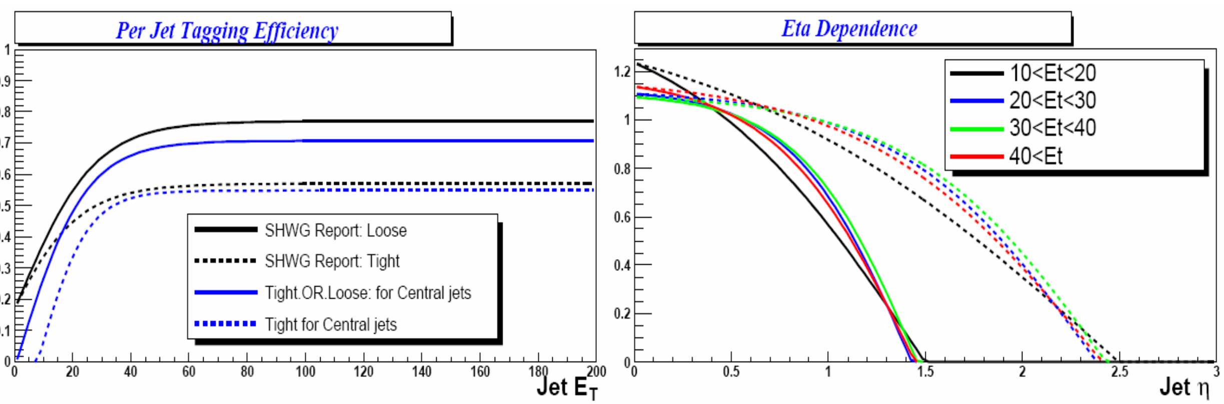
Sensitivity Factors in WH→lvbb

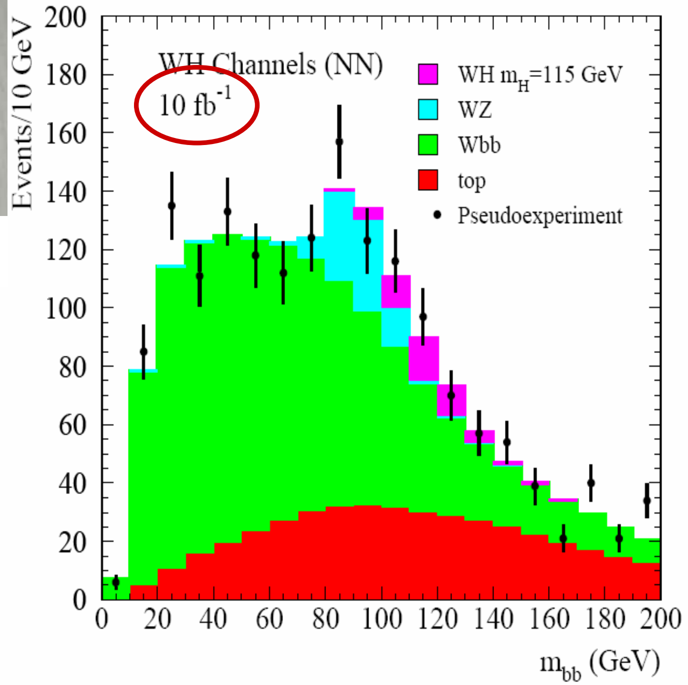
which particularly matters:

- lepton ID efficiency
- b-tagging efficiency
- di-jet mass resolution matters a lot!
  - therefore jet correction is important
  - 2% increase of $\sigma_{M_{bb}}/M_{bb}$ from 10% results in 20% drop of statistic power of threshold integrated luminosity
- neural network's help

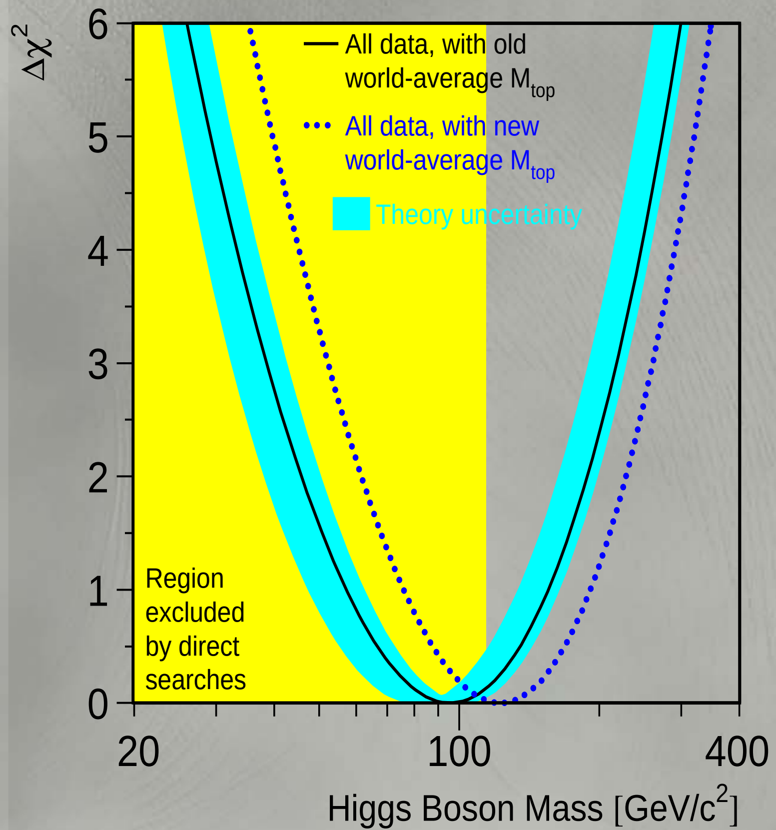


b-tagging improvement from SHWG to THSS





LEP SM Higgs Results



Indirect searches:

- For M_{top} = 174.3 ± 5.1 GeV,
  $\log M_H = 1.98^{+0.21}_{-0.22}$
  $M_H = 96^{+60}_{-38}$ GeV
  M_H < 219 GeV @ 95% CL
- For M_{top} = 178 ± 4.3 GeV,
  $\log M_H = 2.07^{+0.20}_{-0.21}$
  $M_H = 117^{+67}_{-45}$ GeV
  M_H < 251 GeV @ 95% CL

➡ LARGE uncertainties!

LEP2 direct searches: M_H > 114.4 GeV @ 95% CL